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Research Report CCS 516

EFFICIENCY ANALYSIS OF MEDICAL CARE RESOURCES IN THE U.S. ARMY HEALTH SERVICES COMMAND

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July 1985

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This research was partly supported by the U.S. Army Health Services Command and National Science Foundation Grant SES-8408134 with the Center for Cybernetic Studies, The University of Texas at Austin. Reproduction in whole or in part is permitted for any purpose of the United States Government.

CENTER FOR CYBERNETIC STUDIES

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Abstract

Data Envelopment Analysis is a relatively new method for measuring and evaluating the efficiency of not-for-profit entities with multiple outputs and multiple inputs. Without requiring a priori weights and without requiring explicit specification of interdependencies that may be present between variables it (a) provides an overall measure of performance efficiency from observational data and (b) identifies sources and estimates amounts of inefficiency that may be present in each such source. This paper reports on results from studies of DEA for its possible use in evaluating the performance of 24 Army Health Care Facilities. These DEA results are reviewed and compared with results from alternate methods (often used for efficiency analysis) such as statistical regressions and standards imposed by HCFA.

Key Words

Health Care Facilities

Efficiency

Data Envelopment Analysis

Regression/Correlation Analysis

HCFA Reimbursement Standards

1. BACKGROUND

There is a continuing interest in the productivity of US Army health care facilities which has intensified in the past two years. New and improved ways of evaluating performances are therefore being considered. Prior to 1957, average daily bed occupancy was used to evaluate the size and output of Army hospitals, but important problems existed with this measure. First, beds occupied measures only the average number of beds utilized. This measure did not account for the turnover created by patients being admitted and discharged, even though this turnover represented a significant consumption of resources. A second and even more serious problem related to the vast amount of ambulatory care being performed in military health care facilities and this, too, was not explicitly accounted for when using beds occupied.

In 1957, a single output measure was developed called the "Care Composite Unit". This CCU Unit was developed to account for the ambulatory care being performed and the turnover of inpatients.[1] The composite unit used admissions as a surrogate for turnover. In this way one of the inadequacies in the use of average daily beds could be remedied. But it was also necessary to reflect the amount of ambulatory care explicitly and for this a weighted measure for the ambulatory care was used. When finally developed, the Care Composite Unit weighted average daily beds occupied by one and added ten times the number of average daily admissions and 0.3 times the average daily clinic visits. Originally, these weights related well across the entire system at the rate of 100 personnel per 100 Care Composite Units. During three major validation attempts in the past 26 years, CCU showed high

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[1] In civilian hospitals, ambulatory care was handled by physicians in their offices.

correlations to the total system manpower. Over the past ten years, however, a major shift has occurred from hospitalization to treatment on an ambulatory basis and this has led to a reconsideration of the CCU index.

As technology has advanced, imbalances became more prominent and it became increasingly apparent that all clinic visits should not be credited with the same weight nor should all inpatients be credited at the same value during their stay. In searching for alternatives and improvements it was possible to turn to results from the Health Care Financing Agency (HCFA) which had decided to reimburse on the basis of weighted Diagnostic Related Groupings (DRGs) for inpatient care provided to Medicare patients. Although the DRG weights were specifically established for Medicare patients, they did provide a standard for a starting point in identifying differences in the consumption of resources based upon patient diagnoses. Under DRG a discharged patient is classified into a group on the basis of a primary diagnosis and the procedures utilized during the stay. When all such weighted dispositions are summed for a period the result is called the "Relative Weighted Product" (RWP) and serves as a relative measure of the resources consumed by inpatients.

This still left the special features of the Army's ambulatory care activities to be attended to. Currently, the Army is developing a system for ambulatory patients based upon a patient encounter reporting system being tested at six Army facilities. Results of this study should be available by late 1986.

The traditional approach to studying the properties of such measures and reporting systems has been via regression analysis or regression-related correlation analyses. Difficulties arise very quickly in the use of such analytical instruments because of the complex nature of modern health care

delivery. Standard regressions of the single equation at a time variety (with a single dependent variable in each equation) may miss or mask interrelations between outputs and between inputs as well as between inputs and outputs. These relations are often complex and difficult to model in the forms required by standard regression equation formats. For instance, inpatient care is often directly related to outpatient care and resources used in one area may contribute to outputs in another area in many different (often unknown) ways.

Data Envelopment Analysis (DEA), a recently developed method of efficiency evaluation and analysis developed by Charnes, Cooper and Rhodes [12] and [13][1], offered a possible way of dealing with these difficulties. Designed specifically for use in not-for-profit entities with multiple outputs and multiple inputs, DEA does not require explicit identification and formulation of the relations that might obtain between them. Unlike index numbers and other related attempts to obtain relative measures of efficiency, DEA does not require *a priori* weights or other such devices to arrive at overall efficiency evaluations. It also estimates amounts of inefficiency and identifies their possible sources.

Although the product of relatively recent research, DEA has now been tested in a variety of different contexts -- such as those reported in [5] and [9] -- and it therefore seemed worthwhile to undertake further study and tests of DEA for possible use in dealing with problems like those we have already mentioned in evaluating U.S. Army health care facility activities.

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[1] The numbers in square brackets are keyed to the references that appear at the end of this paper.

2. REPORT FORMAT

Table 1 will help to make our subsequent discussion more concrete and meaningful. It represents a report generated in the course of a study of possible uses of DEA undertaken jointly by the Army Health Services Command at Fort Sam Houston in San Antonio with the Center for Cybernetic Studies at The University of Texas at Austin.

This study was based on reports from 24 Army hospitals and other facilities in each of eight quarters, from first quarter 1983 through fourth quarter 1984. In DEA terminology each such facility is referred to as a DMU (Decision Making Unit) indicating that it is responsible, at least in part, for the inputs utilized and outputs produced. In this "prototype study" three outputs and eight inputs were utilized and their values as reported for this particular DMU (= DMU 24) are shown under the column labelled "VALUE MEASURED" in Table 1 as follows:

a. OUTPUTS

(1) PERS TRAIN = Personnel Trained. This included all personnel trained during the quarter except for residents and interns.

(2) RWP = Relative Weighted Product. This is the RWP defined above for which inpatient data used the dispositions reported in the Department of Defense Uniform Chart of Accounts System at the department level (two digit code) multiplied by the HCFA weighted departmental DRG Case Mix Index computed from the Army Inpatient Data System (IPDS) clinical abstract record.

(3) CL VISITS = Clinic Visits. These data represent the total number of encounters made by patients with an ambulatory clinic.

b. INPUTS

(1) CAT 1 FTE = Physicians and Other Primary Care Providers (cat 1 and 2). These data were derived from the Department of Defense Uniform Staffing Methodology (USM) data base and equal the average daily number of full time equivalents (FTE) of physicians and "physician extenders" for time spent treating patients.

(2) CAT 3 FTE = Registered Nurses. The average daily number of full time equivalent registered nurses utilized to treat patients during the quarter.

(3) CAT 4 FTE = Nursing and Administrative/Logistical Personnel (cat 4 and 5). The average daily number of full time equivalents (other than categories 1 through 3) utilized in direct patient care during the period. These data do not include support or overhead personnel such as laboratory, pharmacy, radiology or top managment personnel.

(4) INPAT DLLS = Inpatient Expenditures. The average daily dollars spent by the facility to treat all inpatients.

(5) OUTPAT DLLS = Outpatient Expenditures. The average daily dollars spent to treat all ambulatory patients.

(6) WT PROCED = Weighted Procedures. The average daily number of weighted procedures accomplished in the ancillary work centers utilizing the following weights from the normalized weights of the American College of Pathologists: Radiology (1.4977) Pharmacy (.5717) and Pathology (1.00).

(7) BED DAYS. The average number of daily beds occupied.

(8) OR HOURS = Operating Hours. The average daily number of hours the operating rooms were used.

The actually reported results for each of the above categories for DMU 24 appear in the column under "VALUE MEASURED". We may then turn to the column in Table 1 labelled "VALUE IF EFFICIENT". Considering the behavior of all DMUs in a manner that we shall shortly indicate, DEA identifies only one inefficiency among the outputs. The estimated amount of this inefficiency is shown under the column headed "SLACK" at a value of 6.9 units in the row for PERS TRAIN.[1] That is, instead of training only 36.0 personnel this DMU should have been able to train 42.9 (=36 + 6.9) persons if it were operating efficiently. See the 42.9 opposite PERS TRAIN under the column headed "VALUE IF EFFICIENT".

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[1] Actually the data in this table have been multiplied by a masking factor, as is allowed by DEA because the efficiency ratings are invariant to the units of measure used. See [8].

Turning to the _inputs_, DEA identifies and estimates several further inefficiencies. For instance, with efficient operations (as identified by DEA) DMU No. 24 should have been able to reduce its CAT 1 FTE from 817 to 797.5. This estimate is derived from the overall efficiency value of 0.976 noted at the top of the table by applying it to the observed value of 817 FTE to obtain 0.976 x 817 ≐ 797.5.[1]

The overall efficiency rating of 0.976 applies to _all_ of the inputs in the same manner as was just noted for CAT 1 FTE. In some cases, however, still further input inefficiencies are identified by DEA and listed under the column headed "SLACK". Thus to obtain the 607.2 "VALUE IF EFFICIENT" for CAT 3 FTE, it is not sufficient simply to multiply the 717 in the column "VALUE MEASURED" by 0.976. It is also necessary to reduce the resulting value by the 92.8 SLACK that is present in this input to achieve

$$(0.976 \times 717) - 92.8 \doteq 607.2$$

as shown for CAT 3 FTE in the column labelled "VALUE IF EFFICIENT".

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[1]The symbol "≐" is used to mean "approximately equal" to allow for computer roundoff and like aberrations.

TABLE 1.

A DEA Report

DMU NO. 24

EFFICIENCY = 0.976

FACET:	71	87	95	28	45	20
LAMBDA =	0.378	0.224	0.254	0.313	0.132	0.148

	VALUE MEASURED	VALUE IF EFFICIENT	SLACK
************			
* OUTPUTS *			
************			
PERS TRAIN	36.0	42.9	6.9
RWP	238.0	238.0	0
CL.VISITS	12733.0	12733.0	0
************			
* INPUT *			
************			
CAT 1 FTE	817.0	797.5	0
CAT 3 FTE	717.0	607.2	92.8
CAT 4 FTE	2207.0	2154.4	0
INPAT.DLLS	365440.0	350419.2	0
OUTPAT.DLLS	394297.0	384905.4	6316.5
WT PROCED.	215020.0	139079.4	0
BED DAYS	1397.0	1363.7	70819.2
OR HOURS	436.0	425.6	0
			0

How does DEA arrive at these results? Exact mathematical characterizations and related proofs and interpretations may be found in [8] or [10]. Here we only try to provide a "feel" for the process in the following manner.

As already noted, the present study involved 24 Army Health Care facilities for which complete data were available from the first quarter of 1983 through the fourth quarter of 1984. The data under "VALUE MEASURED" in table 1 are reported activities for DMU 24 in some particular quarter and similar data were available for each of the other DMUs included in the study.

The mathematical processes and computer codes used by DEA search through all DMUs in order to pick a "best" subset for evaluating each of them. The subset thus picked by DEA for evaluating DMU 24 in Table 1 is printed at the top of Table 1 opposite the word FACET. The components in this subset are identified as DMUs 71, 87, 95, 28, 45, and 20 -- with these numbers resulting from the way the individual DMUs were coded for use in the "window analysis" in section 4, below.

These Decision Making Units are all efficient, as determined by DEA, and hence generate an efficiency "facet" for effecting the efficiency evaluation exhibited in Table 1. Other efficiency facets can also be generated by using other sets of efficient Decision Making Units, but this particular facet is chosen by DEA for evaluating DMU 24 because it is the one that gives this DMU the highest efficiency score that the data will allow. In fact the point consisting of the output and input values that result from applying the "lambda" values 0.378, 0.224, 0.214, 0.313, 0.132, and 0.148 to the reported input and output values for the DMUs under which they are listed in Table 1 provides the point of comparison. That is, these

lambda values, as determined by DEA, are used to locate a comparison point in this facet that is used to obtain a relative efficiency rating for DMU 24. No other point in this facet, and *a fortiori* no point in any *other* efficiency facet can give a higher efficiency value to DMU 24 than the 0.976 value listed at the top of Table 1. In other words this is the highest rating that the data allow for scoring the efficiency of DMU 24 in this quarter.

The efficiency rating for DMU 24 in Table 1 is obtained by comparing its behavior with the behavior of other DMUs that are available for this purpose. The value 0.976 thus represents a "relative" efficiency rating. Only Decision Making Units which have relative efficiency ratings of 100% can be used to form these facets and the comparison points from which the DEA evaluations are made. It is against this same point on the efficiency surface that the slack values are also determined and, as we shall later see, other information such as "returns to scale" possibilities may also be obtained from the lambda values in Table 1.

All of the above (and more) is accomplished by DEA and the computer codes used for its implementation.[1] Here we need only note that the efficiency rating as well as the sources and amounts of inefficiency estimated by DEA may be validated not only by reference to the individual DMU being evaluated but also by reference to the DMUs with which it is being compared in this analysis. This is of considerable help to managers and auditors[2]

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[1]Copies of the computer code used in this study may be secured from the Center for Cybernetic Studies at The University of Texas at Austin.

[2]See, e.g., Dennis Thomas [18] for a discussion of the use of DEA in association with on-site management audits by the Texas Public Utility Commission and see Churchill *et al* [15] for an interpretation of PSRO (Professional Standards Review Organizations) as auditors.

(e.g., PSRO review panels) as well as analysts when evaluating and investigating the behavior of particular DMUs. To be sure, these are only estimates. However, DEA appears to be unique among evaluation systems not only in the detail it supplies on each DMU but also in the fact that it evaluates output as well as input inefficiencies in each of them. Note, for example, that efficiency could be achieved by DMU 24 in Table 1 only if this facility <u>decreased</u> its inputs and <u>increased</u> its outputs in the indicated amounts. That is, <u>both</u> must be done to achieve 100% efficiency.

3. MODEL DEVELOPMENT AND DATA COLLECTION

The collection of facets used to obtain these evaluations form what is called an "efficiency evaluation surface" or, more briefly, an "efficiency surface". To continue with this geometric interpretation, we may regard the output and input data for each DMU as corresponding to the values of the coordinates which may be used to locate (or plot) these DMUs in a space with dimensions (or axes) consisting of the three outputs and eight inputs included in this study. Mathematically speaking, the DEA procedures we have just described then generate an "efficiency surface" which envelops these points. Hence, in part, the name Data Envelopment Analysis.

The "lambda" values and the DMUs to which they pertain in Table 1, for instance, identify a point on this efficiency surface from which DMU 24 is evaluated. The input and output values at this point are obtained from DMUs which are efficient. Hence the alternative thus provided can be said to be capable of producing what was produced by DMU 24 and, indeed, even produce more PERS TRAIN with the <u>reduced</u> input amounts noted under "VALUE IF EFFICIENT" in Table 1. All inputs may thus be reduced without reducing any output. Hence no substitutions or tradeoffs need to be made in arriving at

a judgment that DMU 24 is inefficient and that matters will be improved by proceeding in the manner portrayed in Table 1.

All technical matters such as generation and choices of facets for effecting these evaluations are handled by DEA in the form of a mathematical programming model and related computer codes that are already available for these purposes. This leaves analysts and managers free to focus on the choices of inputs and outputs to be utilized and the choices of facilities such as hospitals or subdivisions thereof which are to be regarded as DMUs. See, e.g., D. Sherman [17] for a discussion or his reasons for choosing surgical units within Massachusetts hospitals as DMUs rather than the hospitals themselves for his DEA evaluations.

In the present case only a prototype study was undertaken to evaluate DEA as a possible addition to the Army's methods for evaluating its hospitals and other health services facilities. To facilitate interpretation and evaluation of results the number of outputs and inputs (along with the number of DMUs) was kept to a relatively small number so that computer printouts and other results could be more easily analyzed. This also proved to be advantageous for checking data quality and for studying alternative ways in which the data might be utilized as well as alternative types of data that might be collected.

An example of what might be done with further extensions is provided by reference to the quality of health care services delivered. At present the Army collects data on both patient and physician satisfaction, as well as other attitudinal data that bear on the quality of services rendered and received. Although data like these can be treated as outputs or as inputs

(or both)[1] it would seem better to recognize the complex dimensions of "quality" and to add additional measures that can help to capture these additional aspects of the services rendered. For instance, data on facilities obtained from PSRO reviews, might be used, and even audit follow-ups subsequent to discharge might be used to generate more objective data which could then serve to complement the present subjective evaluations of quality for use in a more extended DEA analysis.

The point is that DEA can accomodate the interdependencies associated with overlapping variables even though such interdependencies are often troublesome to handle in standard forms of statistical regressions. DEA can be (and is) reduced to an ordinary linear programming model for purposes of computation. Hence, the great computational power and efficiency associated with developments in linear programming is avaliable and can be brought to bear for handling large numbers of inputs, outputs and DMUs. Finally, sensitivity analysis and the rich interpretive power available from already completed linear programming research is available for checking data quality in terms of the sensitivity of solutions to possible errors in the data. Hence problems of data collection and refinement can be joined to the research for model development in a twin strategy that can be used to improve and economize both data collection and model development not only in the research but also in the actual use phases of DEA[2].

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[1]Data which appear as both an output and an input are sometimes referred to as intermediate goods. See Chapter IX, pp. 295 ff. in [7] for more precise definitions and characterizations of "intermediate" goods or processes.

[2]See [6] for a detailed descussion of such twin strategies for data collection and model development.

4. WINDOW ANALYSIS

Still other methods of testing and validation are available which have been specifically devised for use in DEA. These methods can also be used to provide results and interpretations which are of interest in their own right.

Table 2 provides an example of such a DEA development which is referred to as a "Window Analysis". The procedures for obtaining such an analysis may be described as follows. Recall, first, that we have eight quarterly reports for each of the 24 DMUs comprehended in this study. In this case it was decided to arrange a four-quarter window analysis with the results displayed in Table 2.

Focusing on DMU 1 in Table 1 we turn to the first row and observe that there are four values ranging from 0.85 to 0.95. These are DEA efficiency ratings of the kind shown for DMU 24 at the top of Table 1. In this case, however, DMU 1 is treated as if it were a different DMU in <u>each</u> of the first four quarters, and the same treatment is accorded to every one of the DMUs in this study. Thus instead of 24 actual DMUs we have 4 x 24 = 96 DMUs for which efficiency ratings are to be secured. The efficiency ratings, one for each quarter, are exhibited for each DMU in the first row so that for DMU 1 we have ratings of 0.85, 0.95, 0.85 and 0.94 in quarters 1, 2, 3, and 4, respectively, as shown in Table 1.

Now suppose the first quarter data are eliminated and replaced by the fifth quarter for each DMU. A new set of efficiency ratings with this new set of DMUs may then be obtained in the same manner as before. This produces the efficiency scores shown in the second row (alongside each DMU) in Table 2.

TABLE 2
EFFICIENCY SCORES

DMU No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	SUMMARY MEASURES MEAN	VAR	COLUMN RANGE	TOTAL RANGE
1	.85	.95	.85	.94					.85	.01	.04	.25
		.96	.86	.95	.81							
			.86	.96	.80	.77						
				.97	.77	.73	.79					
					.79	.74	.80	.84				
2	.80	.77	.72	.72					.75	.00	.12	.15
		.77	.72	.73	.84							
			.69	.69	.72	.79						
				.70	.72	.78	.81					
					.72	.77	.81	.74				
3	.95	.90	.91	.85					.90	.00	.07	.22
		.89	.91	.84	.91							
			.88	.81	.87	.90						
				.78	.86	.93	.94					
					.85	.94	1.00	1.00				
4	.98	.93	.93	1.00					.93	.01	.06	.20
		.93	.93	1.00	.86							
			.90	1.00	.81	1.00						
				1.00	.80	1.00	.92					
					.81	1.00	.91	.82				
5	1.00	1.00	1.00	1.00					.97	.00	.12	.18
		1.00	1.00	1.00	1.00							
			1.00	1.00	1.00	.93						
				.98	.95	.85	1.00					
					.94	.82	1.00	1.00				
6	.89	.83	.84	.86					.88	.00	.12	.18
		.82	.83	.86	.95							
			.83	.85	.94	.89						
				.82	.85	.84	1.00					
					.83	.83	1.00	1.00				
7	1.00	1.00	1.00	1.00					.99	.00	.03	.06
		1.00	1.00	1.00	.96							
			1.00	1.00	.96	1.00						
				1.00	.94	.98	.98					
					.96	1.00	1.00	1.00				
8	.95	.97	.98	1.00					.95	.00	.04	.10
		.94	.94	1.00	.91							
			.94	1.00	.90	1.00						
				1.00	.90	1.00	.98					
					.99	1.00	.98	.92				
9	1.00	1.00	1.00	1.00					.99	.00	.06	.06
		.94	.97	1.00	1.00							
			.97	1.00	1.00	1.00						
				1.00	1.00	.99	1.00					
					1.00	1.00	1.00	1.00				
10	1.00	1.00	1.00	1.00					.98	.00	.11	[illegible]
		1.00	1.00	1.00	1.00							
			1.00	1.00	.99	1.00						
				1.00	.93	1.00	1.00					
11	.92	.98	1.00	1.00					.99	.00	.03	[illegible]
		.98	1.00	1.00	1.00							
			1.00	1.00	1.00	1.00						
				1.00	1.00	.97	1.00					
					1.00	.98	1.00	.93				
12	1.00	1.00	1.00	1.00					.97	.00	.10	.13
		1.00	1.00	1.00	.97							
			1.00	1.00	.91	.94						
				1.00	.90	.93	.95					
					.87	.92	.96	1.00				

EFFICIENCY SCORES

DMU No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	SUMMARY MEASURES: MEAN	VAR	COLUMN RANGE	TOTAL RANGE
13	.98	.91	1.00	.99								
		.91	1.00	.98	.95				.96	.00	.07	.11
			1.00	.97	.94	.93						
				.95	.93	.92	.89					
					.95	.96	.96	1.00				
14	1.00	1.00	1.00	1.00								
		1.00	1.00	1.00	1.00				.99	.00	.08	.08
			1.00	1.00	.97	1.00						
				1.00	.92	.99	1.00					
					.94	.97	1.00	1.00				
15	1.00	1.00	.96	1.00								
		1.00	.96	1.00	.90				.97	.00	.02	.11
			.97	1.00	.90	1.00						
				1.00	.89	1.00	1.00					
					.89	.98	1.00	1.00				
16	.95	1.00	.96	.98								
		1.00	.96	.98	1.00				.96	.00	.12	.12
			.95	.88	.89	1.00						
				.90	.89	1.00	1.00					
					.88	1.00	.98	1.00				
17	.95	1.00	1.00	.97								
		.96	.99	.95	.90				.94	.00	.07	.17
			1.00	.95	.89	.95						
				.97	.84	.94	.93					
					.83	.91	.91	1.00				
18	.96	1.00	1.00	.93								
		1.00	1.00	.99	.98				.99	.00	.05	.07
			1.00	1.00	.97	1.00						
				.98	.95	1.00	1.00					
					.93	.99	1.00	1.00				
19	.85	.89	.89	.73								
		.89	.89	.73	.87				.86	.01	.04	.27
			.88	.73	.86	.84						
				.76	.87	.82	1.00					
					.87	.80	1.00	1.00				
20	.95	1.00	1.00	1.00								
		1.00	1.00	1.00	1.00				1.00	.00	.00	.05
			1.00	1.00	1.00	1.00						
				1.00	1.00	1.00	.97					
					1.00	1.00	.98	1.00				
21	.93	1.00	1.00	1.00								
		1.00	1.00	1.00	.95				.98	.00	.03	.09
			1.00	1.00	.93	1.00						
				1.00	.91	1.00	1.00					
					.93	1.00	1.00	1.00				
22	.75	.87	.80	.77								
		.87	.80	.77	.77				.77	.00	.04	.14
			.80	.76	.75	.77						
				.76	.73	.74	.74					
					.74	.75	.74	.78				
23	.95	1.00	1.00	.96								
		1.00	1.00	.96	1.00				.98	.00	.09	.09
			1.00	.96	.97	1.00						
				1.00	.93	1.00	1.00					
					.91	.99	1.00	1.00				
24	1.00	1.00	1.00	1.00								
		1.00	1.00	1.00	.89				.97	.00	.09	.17
			1.00	1.00	.87	1.00						
				1.00	.83	.99	1.00					
					.88	.91	1.00	1.00				

Returning to Table 1 we can now relate the facet members listed at the top of this table in the following way: DMU 71 the first member listed in the row labelled FACET is actually DMU 23 represented by its third quarter data; DMU 87 represents DMU 15 in terms of its fourth quarter behavior; and so on. To further reenforce what we are saying we might particularly note that DMU 95 is actually DMU 24 itself in the fourth quarter so that DMU 24 is being evaluated in this report for its second quarter behavior by reference to efficient DMUs that include DMU 24 in the third quarter.

We thus obtain an expanded collection of DMUs which can be used to obtain further insight into their behavior and the DEA efficiency ratings that are accorded to them. Proceeding in the manner we have just indicated provides an overlap or "window" which can be used to study the stability of these DEA ratings from the different sets of DMUs that form the reference sets for the ratings in the different rows. Notice, for instance, that the values for DMU 1 are relatively stable in each of the columns (windows) that might be formed to examine its behavior even though different collections of DMUs are available for forming the efficient reference set. We can therefore say that its efficiency ratings are stable in each column even though different reference sets are involved.

Of course the row behavior is also of interest. Notice, for instance, that the efficiency values for all DMUs in column Q5 of Table 2 tend to be low relative to the values in the other columns. This reflects an "after-Christmas" lag in productivity and low workload.

Data inadequacies and possible data errors can also be detected in this manner. For instance large jumps in efficiency values within a column may result from events such as a new policy or turnover and replacement of important members of the staff in a particular DMU. Such behavior can also

result from misreported or erroneous data and these possibilities also need to be considered. See [3] and [5] for further discussion in DEA applications to maintenance activities of the U.S. Air Force. Sherman [17] also reports similar findings of erroneous data and reports in his DEA study of surgical units in Massachussetts hospitals.

The means, variances, and ranges on the right in Table 2 may be used as guides to where underlying DMU behavior might be studied further and perhaps arrayed in more detail in a form such as was exhibited in Table 1 for this purpose. These values can also prove useful in their own right. For instance the mean DEA efficiency of 0.75 shown on the right of Table 2 for DMU 2 is lower than the ratings for any of the other DMUs. Looking into this result in further detail, however, showed that the activities at this facility involved extensive residency and intern training. The PERS TRAIN reported in connection with Table 1 refers to military training and hence does not adequately reflect these other important services provided by DMU 2. Thus this rendering of a low efficiency score for DMU 2 cannot be regarded as wholly valid without the addition of these kinds of outputs and so a future rerun of this study should expand the number of outputs to include residencies and intern training if facilities like DMU 2 are to be covered.

5. EXTENSIONS AND CONCLUSIONS

The preceding analyses and discussions are intended to provide some insight into the nature of DEA as well as the study being undertaken by the Army Health Services Command. In both cases only minimal summaries were given. For instance on the DEA side the discussions accepted the present level of activities at each DMU without considering the possibility of reallocating resources between the different facilities. The latter questions may involve a need to consider possible "economies of scale" for each DMU along with possible further tradeoffs in the input and output mixes that each DMU might use.

The lambda values shown at the top of Table 1 can also be used for this purpose. In particular, as shown in Banker [1], DEA identifies a DMU as being in a region of increasing, constant or decreasing returns to scale according to whether the sum of the lambda values exceeds, is equal to, or less than unity. Thus, here again DEA supplies information that is not readily available from the accounting and ratio controls customarily used by regulatory and other agencies.[1] To illustrate we return to Table 1 and find from the lambda values listed at the top

$$0.378 + 0.224 + 0.254 + 0.313 + 0.132 + 0.148 = 1.449.$$

Since the sum of these lambda values exceeds unity, we find that DEA identifies DMU 24 to be operating in a region of increasing returns to scale.

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[1] See Sherman [17] for a detailed discussion. An analysis of some of the difficulties in the use of statistical regressions may be found in Feldstein [16] although recent developments may help to alleviate some of these difficulties. See Charnes, Cooper and Sueyoshi [14].

To make this more precise we may note that this increasing returns to scale is associated with the comparison point for DMU 24 on the efficiency surface. Recall that this is the point generated from the "lambda" values applied to the facet members listed at the top of Table 1. The adjustments to obtain the "VALUES IF EFFICIENT" in Table 1 position DMU 24 on this point. The fact that the "lambda" values sum to a value greater than unity means that if these efficient input values are increased in a given proportion the resulting movement on this surface will produce a more than proportionate increase in the efficient output values on this part of the efficiency surface. (Conversely, if the inputs were all decreased in a specified proportion then the outputs would decrease more than proportionately.)

Results like these can be of considerable interest to the Army in budgeting and planning its health care activities. The ability of DEA to identify such additional possibilities for each DMU after efficiency has been achieved, makes it an important alternative to the statistical regression techniques that are often used to study the presence of returns to scale possibilities. Banker _et al_ in [2], for example, redid a previous regression study of North Carolina hospitals for returns to scale possibilities. Applying DEA to exactly the same data, Banker and his associates were able to identify many returns to scale situations which the previous regression study had "averaged out" to reach a conclusion that no such possibilities were present.

Of course these types of DEA characterizations and findings need further study and validation before they are put into use. We have described only some of the ways in which it is being examined in the present study.

Other uses and tests are also possible, of course, and these include detailed comparisons with other approaches that are familiar from past experience.

The following figure may be of interest and some of the insights it provides may help us to close this paper on a note that will help to indicate some of the further possibilities. In this case the inpatient costs per Relative Weighted Product (RWP) as defined for output 2 in section 2, above, had already been extensively studied (but just for inpatient costs) by means of standard types of regession-correlation analyses. This therefore provided a convenient comparison test for DEA, parts of which are incorporated in the following figure.

The points in this figure represent DEA estimates of inpatient costs/RWP of selected DMUs from windows 1 and 5. These costs are obtained on the basis of efficient operations by first making the adjustments to "VALUE IF EFFICIENT" in the manner described for Table 1. The plus signs represent regression estimates for inpatient costs/RWP at these same DMUs as obtained from the previously conducted regression studies.

For the eight facilities selected from the regression studies and represented as plus signs in this figure it may be observed that six of them agree with the DEA results.[1] The high regression value within the range of 15 RWP had some specialities not normally associated with a facility of this size -- i.e., extensive oral surgery, gastroenterology and a large orthopedic service -- while the high regression value within the range of 40

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[1] A further detailed discussion and comparison between regressions and DEA via a simulation study may be found in [4] which used the kinds of regressions discussed in [16] for its models.

RWP is associated with DMU 2 which has the exceptional status that was noted earlier.

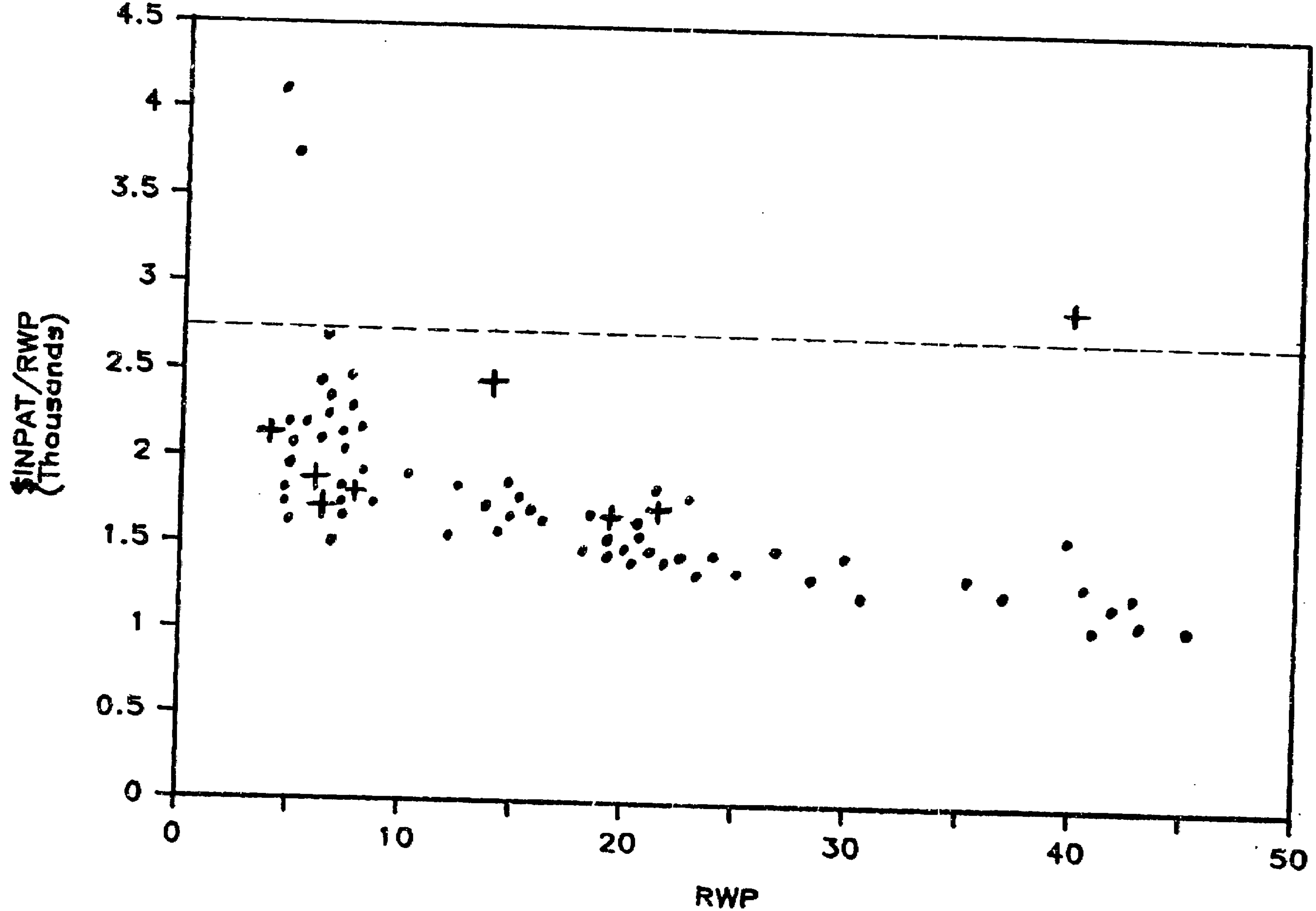
The dashed line shown in the figure represents an approximation to the HCFA reimbursement level using the HCFA unadjusted Federal rate. Interpreted as an efficiency measure (above which compensation will not be paid), it, together with the regression, identifies DMU 2 as inefficient by reference to the regression estimate indicated by the plus sign near 40 RWP. This is perhaps to be expected since, as indicated by the horizontal line, this HCFA level is applicable without respect to volume or mix considerations.

Returning to the issue of increasing returns to scale, it is of interest to see that this is generally born out by the fact that the per unit costs tend to fall with increasing RWP as indicated by the DEA efficiency values represented by the points in the diagram. To be sure, this is only indicative of such increasing returns to scale since the increases in RWP for the DMUs represented in this figure reflect variations in both input and output mixes as well as volume changes in the inputs. This behavior is consistent with the DEA returns to scale characterizations, however, and it should be noted that such behavioral characterizations, which represent additional opportunities for increased efficiency, are not identified in either the regression values or the HCFA reimbursement standard.

Still other possibilities can be (and have been) undertaken in the present study of DEA and more are still to be undertaken. As noted in a recent report to the Army's Health Care Studies and Clinical Investigation Activities: DEA has generated reasonable results for the efficient surfaces used to evaluate multiple input and multiple output systems with very com-

plex interrelationships. Although further analysis is required, the preliminary work to date shows that DEA holds great promise as a method to quickly identify faulty data and to summarize an efficiency surface with advantages for identifying and estimating possible inefficiencies. The limitations of regression and other types of analyses for dealing with multiple outputs and inputs are well known and DEA appears to overcome these deficiencies. Uses of DEA and regression and other techniques in complementary fashion are, of course, also possible. In any case DEA appears to be an extremely valuable technique and should be considered for use by the medical manager and for further research as part of medical information science.

DEA - REGRESSION COMPARISONS WITH
HCFA STANDARDS



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A159742

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: CCS 516	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Efficiency Analysis of Medical Care Resources in the U.S. Army Health Services Command	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): A. Charnes, W.W. Cooper, M. Dieck-Assad, B. Golany, D. Wiggins	8. CONTRACT OR GRANT NUMBER(s): SES-8408134
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Center for Cybernetic Studies, The University of Texas at Austin, Austin, TX 78712	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: National Science Foundation, Washington, D.C. 20550	12. REPORT DATE: July 1985
	13. NUMBER OF PAGES: 27
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Health Care Facilities, Efficiency, Data Envelopment Analysis, Regression/Correlation Analysis, HCFA Reimbursement Standards

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Data Envelopment Analysis is a relatively new method for measuring and evaluating the efficiency of not-for-profit entities with multiple outputs and multiple inputs. Without requiring a priori weights and without requiring explicit specification of interdependencies that may be present between variables it (a) provides an overall measure of performance efficiency from observational data and (b) identifies sources and estimates amounts of inefficiency that may be present in each such source. This paper reports on results from studies of DEA for its possible use in evaluating the performance of 24 Army Health Care Facilities. These DEA results are reviewed and compared with results from alternate methods (often used for efficiency analysis) such as statistical regressions and standards imposed by HCFA.

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